MODIS DATA STUDY TEAM PRESENTATION

April 6, 1990

AGENDA

1. MODIS Performance Requirements as Sized for the Core Data Product Set (Ardanuy)
2. CZCS Processing Code: Levels 0-2 From NOAA/National Marine Fisheries (Gregg)
3. Data Completeness and BER Status Report (McKay)
4. IDS Team Data Product Requirements for MODIS Sorted by Team/Discipline (Hoyt)
5. Simulation of Possible MODIS-T Land Coverage for Building BRDF(Riggs, Gregg)
6. Sizing of Cloud Flagging Procedures (Andrews)
7. Sizing Estimates for Ancillary Data Products (Gregg)
8. Level-3 Processing (Andrews, Schols)

MODIS Performance Requirements as Sized for the Core Data Product Set
Refinements to be added--incomplete as of April 5, 1990 @ 3:40pm.

MODEL I: USES REALISTIC SURFACE COVERAGES

DOMAIN	FRACTION	PROC LEVEL	LOC	MFLOPS		MFLOPS		MFLOPS		COCOMO MODEL	
Day only	40%	Level-1A	40000	25.7	Reproc*2	354.6	Subtotal	572.6			
Ocean only	70%	Level-1B	23925	32.8	NearRT	17.7	Cntl/RDBMS	17.7		Man months	494.4
Land only	30%	L-2 Ocean	11840	23.3	Browse	3.5	Reserve	253.0		Man years	41.2
Cloud only	50%	L-2 Land	42202	7.9	Metadata	1.8	Total	843.3	Year 1		
Clear only	50%	L-2 Atmos	19872	51.4	Maint	17.7	Growth@40%:	1009.6	Year 2		
		Level-2	83914	87.4				1242.3	Year 3		
SCAN PERIOD	SECONDS	Level-3	12000	31.4				1568.1	Year 4		
MODIS-T	4.62	Total	159839	177.3				2024.3	Year 5		
MODIS-N	1.02										

MODEL II: USES MAXIMUM SURFACE COVERAGES

DOMAIN	FRACTION	PROC LEVEL	LOC	MFLOPS		MFLOPS		MFLOPS		COCOMO MODEL	
Day only	100%	Level-1A	40000	25.7	Reproc*2	985.7	Subtotal	1591.9			
Ocean only	100%	Level-1B	23925	48.2	NearRT	49.3	Cntl/RDBMS	49.3		Man months	494.4
Land only	100%	L-2 Ocean	11840	145.9	Browse	9.9	Reserve	703.4		Man years	41.2
Cloud only	100%	L-2 Land	42202	99.5	Metadata	4.9	Total	2344.5	Year 1		
Clear only	100%	L-2 Atmos	19872	137.0	Maint	49.3	Growth@40%:	3081.9	Year 2		
		Level-2	83914	387.5				4114.1	Year 3		
SCAN PERIOD	SECONDS	Level-3	12000	31.4				5559.3	Year 4		
MODIS-T	4.62	Total	159839	492.8				7582.5	Year 5		
MODIS-N	1.02										

[TH.. MODEL (I) USES REALISTIC SURFACE COVERAGES]

		Prototype LOC	Operational LOC	-------Prototype----- MFLOP/Scan MODIS-N	MFLOP/Scan MODIS-T	-------Operational---- MFLOP/Scan MODIS-N	MFLOP/Scan MODIS-T	-------Effective----- MFLOP/Scan MODIS-N	MFLOP/Scan MODIS-T	Resultant MFLOPS MODIS-N&T
Level-1A	Bit Error Correction (to be sized)									
Level-1A	Total	16000	20000	17.8	14.5	22.3	18.1	22.3	18.1	25.7
Level-1B	Navigation	330	513	1.5	1.5	1.5	1.5	1.5	1.5	1.8
Level-1B	Calibration	500	725	29.7	24.2	29.7	24.2	17.2	9.7	18.9
Level-1B	Ancillary	500	725	1.3	3.1	1.3	3.1	1.3	3.1	1.9
Level-1B	Other	8000	10000	9.0	6.0	9.0	6.0	9.0	6.0	10.1
Level-1B	Total	9330	11963	41.5	34.8	41.5	34.8	29.0	20.3	32.8
Level-2	Water-Leaving Radiances	530	1425	16.6	116.9	34.5	236.8	4.8	33.2	11.9
Level-2	Single Scattering Aerosol Radiances	[INCLUDED]	100			1.3	3.0	0.2	0.4	0.3
Level-2	Angstrom Exponents	[INCLUDED]	100			1.3	3.0	0.2	0.4	0.3
Level-2	Chlorophyll-A Concentrations (Case 1	40	200	0.5	1.2	2.3	5.4	0.3	0.8	0.5
Level-2	Chlorophyll-A Concentrations (Case 2	37	193	1.7	3.9	4.7	10.8	0.7	1.5	1.0
Level-2	Chlorophyll-A Fluorescence	100	350	0.4	1.0	2.1	5.0	0.3	0.7	0.4
Level-2	CZCS Pigment Concentrations	18	145	0.4	1.0	2.1	5.0	0.3	0.7	0.4
Level-2	Sea-Surface Temperature	600	1300	6.1		13.5	3.0	4.7	1.1	4.9
Level-2	Sea-Ice Cover	90	280	0.7		2.7	3.0	0.4	0.4	0.5
Level-2	Attenuation at 490 nm	120	400	0.4	1.0	2.1	5.0	0.3	0.7	0.4
Level-2	Detached Coccolith Concentration	100	350	0.8	2.0	2.9	7.0	0.4	1.0	0.6
Level-2	Phycoerythrin Concentrations	150	475	1.1	2.9	3.5	8.8	0.5	1.2	0.7
Level-2	Dissolved Organic Matter	40	200	0.5	1.2	2.3	5.4	0.3	0.8	0.5
Level-2	Seston	40	200	0.5	1.2	2.3	5.4	0.3	0.8	0.5
Level-2	Primary Production	41	203	0.5	1.2	2.3	5.4	0.3	0.8	0.5
Level-2	Land-Leaving Radiances	8261	8361	50.4		50.4		3.0		3.0
Level-2	DEM/DTM	500	1100	7.7		16.7		1.0		1.0
Level-2	Vegetation Index	30	160	4.3		9.9		0.6		0.6
Level-2	Land Surface Temperature	300	700	9.0		19.3		2.9		2.8
Level-2	Thermal Anomalies	100	300	0.7		2.7		0.4		0.4
Level-2	Snow Cover	90	280	0.6		2.5		0.2		0.1
Level-2	Land Cover Type	5000	5100							
Level-2	Bidirectional Reflectance, BRDF	5000	5100							
Level-2	Cloud Mask	200	900	5.0		11.3		11.3		11.1
Level-2	Cloud Fractional Area	100	500	0.6		2.5		2.5		2.5
Level-2	Cloud-Top Temperature and Pressure	424	948	8.6		18.5		9.3		9.1
Level-2	Cloud Optical Thickness (0.66 μm)	1080	1180	25.0		25.0		5.0		4.9
Level-2	Cloud Particle Effective Radius	[INCLUDED]	100			1.3		0.3		0.3
Level-2	Cloud Particle Thermodynamic Phase	[INCLUDED]	100			1.3		0.3		0.3
Level-2	Aerosol Optical Depth (0.41 to 2.13	500	1100	3.1		7.5		1.5		1.5
Level-2	Aerosol Size Distribution	704	1508	29.2		59.8		12.0		11.7
Level-2	Aerosol Mass Loading	100	300	0.7		2.7		0.5		0.5
Level-2	Atmospheric Stability	3000	3100	8.6		8.6		8.6		8.4
Level-2	Total Precipitable Water	[INCLUDED]	100			1.3				
Level-2	Total Ozone	[INCLUDED]	100			1.3		1.3		1.3
Level-2	Other	4000	5000	4.5	3	4.5	3.0	4.5	1.2	4.7
Level-2	All	31295	41957	188	136	327	315	79	46	87
Level-3	Averaging	1000	2000	5.6		11.2		11.2		11.2
Level-3	Other	2000	4000	10.1		20.2		20.2		20.2
Level-3	All	3000	6000	15.7		31.4		31.4		31.4

[THIS MODEL (II) USES MAXIMUM SURFACE COVERAGES]

		Prototype LOC	Operational LOC	-------Prototype----- MFLOP/Scan MODIS-N	MFLOP/Scan MODIS-T	-------Operational---- MFLOP/Scan MODIS-N	MFLOP/Scan MODIS-T	-------Effective----- MFLOP/Scan MODIS-N	MFLOP/Scan MODIS-T	Resultant MFLOPS MODIS-N&T
Level-1A	Bit Error Correction (to be sized)									
Level-1A	Total	16000	20000	17.8	14.5	22.3	18.1	22.3	18.1	25.7
Level-1B	Navigation	330	513	1.5	1.5	1.5	1.5	1.5	1.5	1.8
Level-1B	Calibration	500	725	29.7	24.2	29.7	24.2	29.7	24.2	34.4
Level-1B	Ancillary	500	725	1.3	3.1	1.3	3.1	1.3	3.1	1.9
Level-1B	Other	8000	10000	9.0	6.0	9.0	6.0	9.0	6.0	10.1
Level-1B	Total	9330	11963	41.5	34.8	41.5	34.8	41.5	34.8	48.2
Level-2	Water-Leaving Radiances	530	1425	16.6	116.9	34.5	236.8	34.5	236.8	85.1
Level-2	Single Scattering Aerosol Radiances	[INCLUDED]	100			1.3	3.0	1.3	3.0	1.9
Level-2	Angstrom Exponents	[INCLUDED]	100			1.3	3.0	1.3	3.0	1.9
Level-2	Chlorophyll-A Concentrations (Case 1	40	200	0.5	1.2	2.3	5.4	2.3	5.4	3.4
Level-2	Chlorophyll-A Concentrations (Case 2	37	193	1.7	3.9	4.7	10.8	4.7	10.8	6.9
Level-2	Chlorophyll-A Fluorescence	100	350	0.4	1.0	2.1	5.0	2.1	5.0	3.1
Level-2	CZCS Pigment Concentrations	18	145	0.4	1.0	2.1	5.0	2.1	5.0	3.1
Level-2	Sea-Surface Temperature	600	1300	6.1		13.5	3.0	13.5	3.0	13.9
Level-2	Sea-Ice Cover	90	280	0.7		2.7	3.0	2.7	3.0	3.3
Level-2	Attenuation at 490 nm	120	400	0.4	1.0	2.1	5.0	2.1	5.0	3.1
Level-2	Detached Coccolith Concentration	100	350	0.8	2.0	2.9	7.0	2.9	7.0	4.4
Level-2	Phycoerythrin Concentrations	150	475	1.1	2.9	3.5	8.8	3.5	8.8	5.3
Level-2	Dissolved Organic Matter	40	200	0.5	1.2	2.3	5.4	2.3	5.4	3.4
Level-2	Seston	40	200	0.5	1.2	2.3	5.4	2.3	5.4	3.4
Level-2	Primary Production	41	203	0.5	1.2	2.3	5.4	2.3	5.4	3.4
Level-2	Land-Leaving Radiances	8261	8361	50.4		50.4		50.4		49.4
Level-2	DEM/DTM	500	1100	7.7		16.7		16.7		16.4
Level-2	Vegetation Index	30	160	4.3		9.9		9.9		9.7
Level-2	Land Surface Temperature	300	700	9.0		19.3		19.3		18.9
Level-2	Thermal Anomalies	100	300	0.7		2.7		2.7		2.6
Level-2	Snow Cover	90	280	0.6		2.5		2.5		2.5
Level-2	Land Cover Type	5000	5100							
Level-2	Bidirectional Reflectance, BRDF	5000	5100							
Level-2	Cloud Mask	200	900	5.0		11.3		11.3		11.1
Level-2	Cloud Fractional Area	100	500	0.6		2.5		2.5		2.5
Level-2	Cloud-Top Temperature and Pressure	424	948	8.6		18.5		18.5		18.1
Level-2	Cloud Optical Thickness (0.66 μm)	1080	1180	25.0		25.0		25.0		24.5
Level-2	Cloud Particle Effective Radius	[INCLUDED]	100			1.3		1.3		1.3
Level-2	Cloud Particle Thermodynamic Phase	[INCLUDED]	100			1.3		1.3		1.3
Level-2	Aerosol Optical Depth (0.41 to 2.13	500	1100	3.1		7.5		7.5		7.4
Level-2	Aerosol Size Distribution	704	1508	29.2		59.8		59.8		58.6
Level-2	Aerosol Mass Loading	100	300	0.7		2.7		2.7		2.6
Level-2	Atmospheric Stability	3000	3100	8.6		8.6		8.6		8.4
Level-2	Total Precipitable Water	[INCLUDED]	100			1.3				
Level-2	Total Ozone	[INCLUDED]	100			1.3		1.3		1.3
Level-2	Other	4000	5000	4.5	3	4.5	3.0	4.5	3.0	5.1
Level-2	All	31295	41957	188	136	327	315	326	315	387
Level-3	Averaging	1000	2000	5.6		11.2		11.2		11.2
Level-3	Other	2000	4000	10.1		20.2		20.2		20.2
Level-3	All	3000	6000	15.7		31.4		31.4		31.4

Considerations and Assumptions

1. With a few exceptions, the estimated lines of code (LOC) as sized by the MODIS Data Study Team (prototype) have been doubled to include operational error trapping, other condition checks, etc.

2. When MODIS-N and MODIS-T both use the "same" code, then the LOC is increased by 25%.

3. The prototyped MFLOPS are scaled by a factor of two when an operational adjustment is made to the estimated LOC to reflect the increased performance requirements caused by the additional complexity.

4. In the summary ONLY, the LOC are doubled to account for comments.

5. A coverage matrix is applied to each product to get an effective number of operations per scan that accounts fro fraction of daylight, ocean. land, and cloud.

6. The most demanding atmospheric data products are retrieved at Level-2 only at a 1/25 resolution (every 5 km in each dimension).

7. The annual growth at 40% is applied to the Level-2 component only.

8. As a very new development, the driving requirement that temperature/moisture soundings be taken with MODIS data using the TOVS processing package has been dropped. This alteration is based on the recommendation of Mike King, and substantially lowers the processing requirement.

9. Calibration, as sized, assumes a moderately simple procedure to correct counts to radiances at the satellite (i.e., gain, offset, and temperature dependence).

10. 100 LOC are added to each product for QC. In addition, 100 operations are applied to each pixel for each product, but not for each spectral band. Accordingly, 1.3 and 3 MFLOPs are added to the operational performance for each MODIS-N and -T scan.

11. LOC expands as follows (consider Case-1 Chlorophyll-A Concentrations prototyped at 40 LOC. Because -N and -T are used, multiply by 1.25 --> 50 LOC. Because we are being conservative, we consider this "immature" code and multiply by 2 --> 100 LOC. To consider QC, we add 100 LOC for the product --> 200 LOC.

12. We were initially surprised by the relatively low size of ocean Level-2 data products (11,840 LOC, and an earlier estimate of 8,840 LOC that did not consider QC), particularly as we have built in two factors of 2: the first for "immaturity" and the second for in-line comments/prologue. However, appended is the complete CZCS processing code for Levels-0, 1A, 1B, and 2. This code is operational as written by the NOAA National Marine Fisheries during the mid-1980's. The code is 1,886 lines including about 50% comment lines, of which only 32% (about 600 lines) is Level-2. The code generates two products: Water-Leaving Radiances, which we have sized at 530 to 1,425 LOC before comments (2,850 after), and Level-2 CZCS Pigment Concentrations, which we have sized at 18 to 145 LOC before comments (290 after). Note that our conservative approach yields:

	MODIS-era		CZCS-era
2850 + 290 =	3,140	>>	600

COVERAGE MATRIX FOR DATA PRODUCT TYPES

		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Water-Leaving Radiances	1	1	0	0	1
Level-2	Single Scattering Aerosol Radiances	1	1	0	0	1
Level-2	Angstrom Exponents	1	1	0	0	1
Level-2	Chlorophyll-A Concentrations (Case 1)	1	1	0	0	1
Level-2	Chlorophyll-A Concentrations (Case 2)	1	1	0	0	1
		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Chlorophyll-A Fluorescence	1	1	0	0	1
Level-2	CZCS Pigment Concentrations	1	1	0	0	1
Level-2	Sea-Surface Temperature	0	1	0	0	1
Level-2	Sea-Ice Cover	1	1	0	0	1
Level-2	Attenuation at 490 nm	1	1	0	0	1
		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Detached Coccolith Concentration	1	1	0	0	1
Level-2	Phycoerythrin Concentrations	1	1	0	0	1
Level-2	Dissolved Organic Matter	1	1	0	0	1
Level-2	Seston	1	1	0	0	1
Level-2	Primary Production	1	1	0	0	1
		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Land-Leaving Radiances	1	0	1	0	1
Level-2	DEM/DTM	1	0	1	0	1
Level-2	Vegetation Index	1	0	1	0	1
Level-2	Land Surface Temperature	0	0	1	0	1
Level-2	Thermal Anomalies	0	0	1	0	1
		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Snow Cover	1	0	1	0	1
Level-2	Land Cover Type	1	0	1	0	1
Level-2	Bidirectional Reflectance, BRDF	1	0	1	0	1
Level-2	Cloud Mask	0	0	0	0	0
Level-2	Cloud Fractional Area	0	0	0	0	0
		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Cloud-Top Temperature and Pressure	0	0	0	1	0
Level-2	Cloud Optical Thickness (0.66 μm)	1	0	0	1	0
Level-2	Cloud Particle Effective Radius	1	0	0	1	0
Level-2	Cloud Particle Thermodynamic Phase	1	0	0	1	0
Level-2	Aerosol Optical Depth (0.41 to 2.13 μm)	1	0	0	0	1
		Day Only	Ocean only	Land only	Cloud only	Clear only
Level-2	Aerosol Size Distribution	1	0	0	0	1
Level-2	Aerosol Mass Loading	1	0	0	0	1
Level-2	Atmospheric Stability	0	0	0	0	0
Level-2	Total Precipitable Water	0	0	0	0	0
Level-2	Total Ozone	0	0	0	0	0

QUASI-INDEPENDENT "RED TEAM" ESTIMATE OF MODIS PROCESSING REQUIREMENTS

General information:	maximum pix/sec	channels	daytime tot/sec	nighttime tot/sec
MODIS-N pixels/sec/lambda (visible 1 km):	12656	12	151872	0
MODIS-N pixels/sec/lambda (thermal 1 km):	12656	17	215152	215152
MODIS-N pixels/sec/lambda (0.5 km):	50624	5	253120	0
MODIS-N pixels/sec/lambda (0.25 km.):	202496	2	404992	0
MODIS-T pixels/sec/lambda (1.1 km):	6784	32	217088	0
			1242224	215152
Percent computer usage:		70.0		
Percent downtime:		10.0		
Percent browse overhead:		0.1		
Percent metadata overhead:		0.2		
Percent I/O overhead:		20.0		
Number of reprocessings:		2		
Calculated overhead above Level 2:		3.77		
Assumed day/night duty cycle:		0.5		
Assumed fractional cloud cover:		0.5		
Assumed fractional land cover:		0.3		
Assumed fractional ocean cover:		0.7		

	Mflops:	Ops/pix:	Pix/sec:	no. of products	no. of inputs
BASIC LEVEL 1A PROCESSING:					
MODIS-N (visible 1 km):	1.14	15	6328	12	12
MODIS-N (thermal 1 km):	3.23	15	12656	17	17
MODIS-N (0.5 km):	1.90	15	25312	5	5
MODIS-N (0.25 km):	3.04	15	101248	2	2
MODIS-T (1.1 km):	1.63	15	3392	32	32
BASIC LEVEL 1B PROCESSING:					
MODIS-N (visible 1 km):	2.64	35	6328	12	12
MODIS-N (thermal 1 km):	5.16	24	12656	17	17
MODIS-N (0.5 km):	3.80	30	25312	5	5
MODIS-N (0.25 km):	8.50	42	101248	2	2
MODIS-T (1.1 km):	2.66	25	3392	32	32
LAND LEVEL 2 PROCESSING:					
Land leaving radiances (8):	3.80	500	949	8	9
NDVI(1 km):	0.00	0	949	1	2
NDVI(0.5 km):	0.00	0	3797	1	2
NDVI(0.25 km):	0.61	20	30374	1	2
Land surface temperature (LST):	2.66	1400	1898	1	3
Land cover type:	0.67	44	15187	1	2
Weekly global snowcover maps:	0.04	44	949	1	3
Thermal anomalies and fires:	1.32	52	12656	2	4
Surface spectral albedo maps (8):	0.00	0	949	8	9
OCEAN LEVEL 2 PROCESSING:					
Water leaving radiances (32):	11.16	126	2215	40	40
Single scattering aerosol radiance:	0.00	0	2215	1	1
Angstrom coefficient:	0.00	0	2215	1	3
Chlorophyll-a conc.(case 1 waters):	0.09	39	2215	1	2
Chlorophyll-a conc.(case 2 waters):	0.01	130	111	1	2
Chlorophyll fluorescence:	0.22	100	2215	1	3
CZCS pigment concentrations:	0.08	34	2215	1	2
Sea surface temperature:	3.10	700	4430	1	3
Detached coccolith concentrations:	0.09	40	2215	1	4
Phycoerythrin pigment concentration:	0.12	52	2215	1	2
Dissolved organic material conc.:	0.09	39	2215	1	2
Attenuation in oceans at 490 nm:	0.22	100	2215	1	1
Total seston concentrations:	0.09	39	2215	1	2
Primary productivity (case 1):	0.09	41	2215	1	4
In-situ validation observations:	0.22	100	2215	1	1

OSPHERIC LEVEL 2 PROCESSING:

Cloud opt. depth, drop size & phase:	12.91	51000	253	1	8
Cloud properties: Emis., T, and P:	0.76	3000	253	1	8
Cloud flags:	6.33	500	12656	1	4
Aerosol optical depth (8):	0.06	63	127	8	8
Aerosol size distribution (8):	28.91	28549	127	8	12
Total column ozone:	0.00	100	5	1	18
Total precipitable water:	0.00	100	5	1	18
Lifted index:	0.00	100	5	1	18
Layer mean temperatures:	4.30	850000	5	1	18
Layer mean moisture:	4.30	850000	5	1	18
Total number of Level 2 products:				238	374

LEVEL 2 TO 3 PROCESSING:

				# rect.
LAND PRODUCTS:				
MODIS-N (visible 1 km):	6.71	372	949	19
MODIS-N (thermal 1 km):	2.12	372	1898	3
MODIS-N (0.5 km):	2.82	372	7594	1
MODIS-N (0.25 km):	11.30	372	30374	1
OCEAN PRODUCTS:				
MODIS-T (1.1 km):	6.62	372	1187	15
ATMOSPHERIC PRODUCTS:				
MODIS-N (visible 1 km):	1.88	372	253	20
MODIS-N (thermal 1 km):	2.26	372	506	12
MODIS-N (0.5 km):	0.00	372	12656	0
MODIS-N (0.25 km):	0.00	372	50624	0

	Mflops	With % use Mflops	Cum. sum Mflops	Data Volume Gpix/day	Cum. sum Volume
el 1A processing (w/o DTM):	10.93	15.61	15.61	62.96	62.96
Level 1A processing (DTM overhead):	4.96	7.09	22.70	0.00	
Level 1B processing:	22.77	32.52	55.23	62.96	125.92
Land Level 2 processing:	9.09	12.98	68.21	8.09	134.01
Ocean Level 2 processing:	15.57	22.24	90.46	10.34	144.35
Atmospheric level 2 processing:	57.57	82.25	172.70	1.31	145.67
Level 2 to level 3 processing:	33.72	48.17	220.87	7.83	153.50
Level 3 to level 4 processing:	0	0.00	220.87	0.00	153.50
Browse processing:	0.15	0.22			
Metadata processing:	0.31	0.44			
I/O overhead:	31.02	44.31			
Downtime overhead:	18.61	26.58			
Twice reprocessing:	409.40	584.86			
Storage required (Gpix/day):				153.50	
Grand total of processing (MFLOPS):		877.29	833.01		
Grand total of processing (GFLOPS):		0.88	0.83		

Grand total (UARS analog, method 1; GFLOPS): 17.49 Assumes UARS CDHF=6.4 Mflop.

Grand total (UARS analog, method 2; GFLOPS): 17.49 Assumes MODIS has 24000 ops/pix

Grand total as function of N ops/pixel (GFLOPS):		N ops/pix
	1.46	2000
	2.91	4000
	4.37	6000
	5.83	8000

ɪMARY ESTIMATE OF MODIS CDHF REQUIREMENTS:

	N	MFLOPS /var. with no overhead	Total	Total + overhead
Level 0 to 1A:	66	0.24	15.89	30.06
Level 1A to 1B:	66	0.34	22.77	43.06
Land variables:	24	0.38	9.09	17.19
Ocean variables:	54	0.29	15.57	29.45
Atmospheric vars:	24	2.40	57.57	108.89
Level 3:			33.72	63.78
Total (MFLOPS):			154.61	292.43
Re-processing (MFLOPS):				584.86
Grand total (GFLOPS):				0.88

Status Report on Data Completeness and BER

1. Contacted Art Jackson (Code 533.0) for information on TDRSS performance. Expected TDRSS uncorrected bit error rate is 10^{-5} or less, probably less.

Coding handled under CDOS direction. Referred me to Dr. Stan Sobieski (Code 502.0) for information on coding performance.

2. Contacted Stan Sobieski. Increasing recognition that present CCSDS standards do not adequately define data completeness requirements. Probable revision in CCSDS standards to provide better definition and control of data completeness.

If really important to get straight project info, suggested that I talk with his Chief Engineer, Madeline Butler (Code 531.3), after her return from Marshall on Monday, April 9.

3. Only appropriate CCSDS contact at NASA headquarters - Ed Greene. In Europe until Monday, April 16.

POSSIBLE INTERDISCIPLINARY INVESTIGATOR DATA PRODUCT REQUIREMENTS FOR MODIS SORTED BY INVESTIGATORS

Abbott	Phytoplankton pigment
Abbott	Surface incident radiation
Abbott	Light attenuation
Abbott	Primary production (integrated)
Abbott	Primary production (near surface)
Abbott	Dissolved organic matter
Abbott	Phycoerythrin
Abbott	Sea surface temperature
Abbott	Fluorescence yield
Barron	Land surface skin temperature
Barron	Snow extent
Barron	Leaf area index
Barron	Tropospheric temperature profile
Barron	Ocean surface water temperature
Barron	Vegetation - land cover type
Barron	Surface water cover
Barron	Sea ice extent
Batista/Richey	Precipitable water
Batista/Richey	Tropospheric vapor
Batista/Richey	Surface temperature
Batista/Richey	Radiation fluxes
Batista/Richey	Vegetation biomass
Brewer	Primary production
Brewer	Dissolved organic carbon
Brewer	Diffuse attenuation coefficient
Brewer	UV incident irradiance
Brewer	Visible incident irradiance
Brewer	Ocean color data
Dozier	Snow spectral albedo
Dozier	Snow covered area
Hartmann	Broadband radiative energy fluxes at surface
Hartmann	Sea surface temperature
Hartmann	Cloud optical depth
Hartmann	Cloud particle size distributions
Hartmann	Mesoscale cloud structure

Isacks	Areal extent of vegetation types
Isacks	Vegetation indices
Isacks	Proportion bare soil
Isacks	Skin temperature
Isacks	Tropospheric temperature profile
Isacks	Precipitation rate
Isacks	Humidity profile
Isacks	Cloud cover
Isacks	Snow cover extent
Isacks	Glacier extent
Isacks	Extent of surface water
Kerr	Soil temperature
Kerr	Vegetation temperature
Kerr	Rain rate
Kerr	Surface longwave flux
Kerr	Cloud cover
Kerr	Cloud emission temperature
Kerr	Temperature profile
Kerr	Actual evapotranspiration
Kerr	Proportion bare soil
Kerr	Vegetation type
Kerr	Vegetation condition
Kerr	Vegetation transpiration
Kerr	Photosynthetically active radiation
Kerr	Vegetation integrated water content
Kerr	Monthly precipitation
Kerr	Surface shortwave fluxes
Kerr/Sorooshian	Plant distribution
Kerr/Sorooshian	Vegetation BRDF
Kerr/Sorooshian	Vegetation indices
Liu	Sea surface temperature
Moore	Precipitation as snow
Moore	Snow extent and water content
Moore	Floodplain extent and inundation
Moore	Topography
Moore	Vegetation type
Moore	Vegetation indices
Moore	Evapotranspiration
Moore	Photosynthetically active radiation
Moore	Land cover
Moore	Burning indices
Moore	Above surface biomass
Moore	Surface litter
Moore	Proportion of bare soil
Moore	Soil moisture
Moore	Total chlorophyll
Moore	Leaf/canopy water content
Moore	Non-photosyntheticpigment(tannin,anthocyanin)
Moore	Canopy nitrogen

Mouganis-Mark	Eruption detection via thermal spikes
Mouganis-Mark	Eruption detection via SO2 spike
Mouganis-Mark	Eruption plume temperature
Mouganis-Mark	Eruption plume height
Mouganis-Mark	Eruption plume dispersal rate
Mouganis-Mark	Eruption plume ash fall-out rate
Mouganis-Mark	Eruption plume SO2 content
Mouganis-Mark	Eruption plume ash chemistry
Rothrock	Sea ice surface temperature
Rothrock	Sea ice albedo
Rothrock	Sea surface temperature
Rothrock	Pigment (oceans)
Schimel	Incident PAR
Schimel	Chlorophyll density
Schmiel	Leaf area index
Sorooshian	Vegetation indices
Sorooshian	Canopy temperature
Sorooshian	PAR
Sorooshian	Soil brightness index
Sorooshian	Soil BRDF
Sorooshian	Vegetation BRDF
Srokosz	Sea surface temperature
Srokosz	Chlorophyll
Srokosz	MODIS radiances (all bands)
Wielicki	Sea surface temperatures
Wielicki	Land surface skin temperature
Wielicki	Land surface emissivity (8-12 micron)
Wielicki	Snow/ice background
Wielicki	Longwave top of atmosphere flux
Wielicki	Shortwave top of atmosphere flux
Wielicki	Longwave surface fluxes (up, down, net)
Wielicki	Radiative flux divergence for atmosphere
Wielicki	Cloud fraction
Wielicki	Cloud top altitude
Wielicki	Cloud bottom altitude
Wielicki	Cloud water phase
Wielicki	Cloud particle size
Wielicki	Cloud optical depth
Wielicki	Cloud water content
Wielicki	Broadband BRDF

POSSIBLE INTERDISCIPLINARY INVESTIGATOR DATA PRODUCT REQUIREMENTS FOR MODIS SORTED BY DISCIPLINE

LAND:

LAND COVER TYPES, AREAL COVERAGE, AND INDICES:

Isacks	Vegetation indices
Kerr/Sorooshian	Vegetation indices
Moore	Vegetation indices
Sorooshian	Vegetation indices
Schmiel	Leaf area index
Barron	Leaf area index
Moore	Vegetation type
Moore	Land cover
Isacks	Areal extent of vegetation types
Barron	Vegetation - land cover type
Kerr	Vegetation type
Kerr/Sorooshian	Plant distribution
Isacks	Proportion bare soil
Kerr	Proportion bare soil
Moore	Proportion of bare soil

SURFACE WATER EXTENT:

Barron	Surface water cover
Isacks	Extent of surface water
Moore	Floodplain extent and inundation

SNOW AND GLACIAL EXTENT:

Barron	Snow extent
Dozier	Snow covered area
Isacks	Snow cover extent
Moore	Snow extent and water content
Wielicki	Snow/ice background
Isacks	Glacier extent

LAND SURFACE TEMPERATURES AND SURFACE EMISSIVITY:

Barron	Land surface skin temperature
Wielicki	Land surface skin temperature
Batista/Richey	Surface temperature
Isacks	Skin temperature
Kerr	Vegetation temperature
Sorooshian	Canopy temperature
Kerr	Soil temperature
Sorooshian	Soil brightness index
Wielicki	Land surface emissivity (8-12 micron)

PRECIPITATION AND WATER:

Kerr	Monthly precipitation
Moore	Precipitation as snow
Moore	Evapotranspiration
Kerr	Actual evapotranspiration
Kerr	Vegetation transpiration
Moore	Leaf/canopy water content
Kerr	Vegetation integrated water content
Moore	Soil moisture

RADIATION BUDGET COMPONENTS:

Kerr	Photosynthetically active radiation
Moore	Photosynthetically active radiation
Schimel	Incident PAR
Sorooshian	PAR
Kerr	Surface longwave flux (over land)
Kerr	Surface shortwave fluxes
Batista/Richey	Radiation fluxes (over land?)
Dozier	Snow spectral albedo

BRDF:

Kerr/Sorooshian	Vegetation BRDF
Sorooshian	Vegetation BRDF
Sorooshian	Soil BRDF
Wielicki	Broadband BRDF

VOLCANOES:

Mouganis-Mark	Eruption detection via thermal spikes
Mouganis-Mark	Eruption detection via SO2 spike
Mouganis-Mark	Eruption plume temperature
Mouganis-Mark	Eruption plume height
Mouganis-Mark	Eruption plume dispersal rate
Mouganis-Mark	Eruption plume ash fall-out rate
Mouganis-Mark	Eruption plume SO2 content
Mouganis-Mark	Eruption plume ash chemistry

BIOMASS AND ITS CHEMISTRY:

Batista/Richey	Vegetation biomass
Moore	Above surface biomass
Moore	Total chlorophyll
Schimel	Chlorophyll density
Moore	Non-photosyntheticpigment(tannin,anthocyanin)
Moore	Canopy nitrogen
Kerr	Vegetation condition
Moore	Surface litter
Moore	Burning indices

OCEANS:

SEA SURFACE TEMPERATURE:

Abbott	Sea surface temperature
Barron	Ocean surface water temperature
Hartmann	Sea surface temperature
Liu	Sea surface temperature
Rothrock	Sea surface temperature
Srokosz	Sea surface temperature
Wielicki	Sea surface temperatures

PIGMENTS:

Abbott	Phytoplankton pigment
Abbott	Dissolved organic matter
Abbott	Phycoerythrin
Abbott	Fluorescence yield
Brewer	Dissolved organic carbon
Rothrock	Pigment (oceans)
Srokosz	Chlorophyll

SURFACE RADIATION FLUXES:

Abbott	Surface incident radiation
Abbott	Light attenuation
Brewer	Diffuse attenuation coefficient
Brewer	UV incident irradiance
Brewer	Visible incident irradiance
Brewer	Ocean color data
Hartmann	Broadband radiative energy fluxes at surface
Srokosz	MODIS radiances (all bands)

PRIMARY PRODUCTION AND BIOLOGICAL ACTIVITY:

Abbott	Primary production (integrated)
Abbott	Primary production (near surface)
Brewer	Primary production

SEA ICE:

Barron	Sea ice extent
Rothrock	Sea ice surface temperature
Rothrock	Sea ice albedo

ATMOSPHERE:

CLOUDS:

Wielicki	Cloud fraction
Isacks	Cloud cover (over land)
Kerr	Cloud cover (over land)
Hartmann	Cloud optical depth
Wielicki	Cloud optical depth
Hartmann	Cloud particle size distributions
Wielicki	Cloud particle size
Kerr	Cloud emission temperature (over land)
Wielicki	Cloud top altitude
Wielicki	Cloud bottom altitude
Hartmann	Mesoscale cloud structure

PRECIPITATION, MOISTURE, AND WATER:

Batista/Richey	Precipitable water
Isacks	Precipitation rate (over land)
Kerr	Rain rate (over land)
Isacks	Humidity profile (over land)
Batista/Richey	Tropospheric vapor
Wielicki	Cloud water phase
Wielicki	Cloud water content

TEMPERATURES:

Barron	Tropospheric temperature profile
Isacks	Tropospheric temperature profile (over land)
Kerr	Temperature profile (over land)

RADIATION BUDGET AND FLUXES:

Wielicki	Longwave top of atmosphere flux
Wielicki	Longwave surface fluxes (up, down, net)
Wielicki	Shortwave top of atmosphere flux
Wielicki	Radiative flux divergence for atmosphere

6 April 1990

MODIS-T Land Coverage Possible for Building a BRDF

We have simulated global land coverage of MODIS-T for a "CZCS tilt strategy" with the restriction that for any scan containing ocean the sensor is set to ocean mode, assuming at that time that MODIS-T would operate in dual mode. The results of that simulation are presented in the MODIS Data Study Team Presentation, 23 March 1990. Here those results are examined to determine the potential number of multiple images, of the same surface location, that might be acquired by MODIS-T given the restrictions and assumptions of the simulation. These results are then examined in response to the report that MODIS-T will operate in composite mode. Also, a simulation is currently being performed to determine land regions where MODIS-T could be operated in stare mode; collecting data for a surface bidirectional reflectance distribution function--without sacrificing ocean coverage.

Land Coverage Useful for BRDF

Of principal interest to the land scientists is the ability to use MODIS-T data to determine surface directional reflectance features, specifically the surface bidirectional reflectance distribution function (BRDF) which is considered an intrinsic property of the surface. Determination of surface directional reflectance properties and the BRDF require reflectance data acquired at different sun-surface-sensor geometries. The tilting ability of MODIS-T may provide some of this data, given that the coverage over land is adequate. What is required for determining surface directional reflectance features is a MODIS-T data set over a surface feature at different tilt and viewing angles constructed from multiple MODIS-T images of the surface. Which raises the question of how much data on surface directional reflectance could be obtained with MODIS-T from our simulated coverage.

The large amount of land coverage in the composite image (Figure 1) for our simulation is immediately apparent. What is not immediately apparent is that in some areas this composite coverage is the result of only a single swath of coverage in the 16 day repeat cycle, of the platform. This is especially true of the coastal regions and this coverage is along the edge of a swath. For example this is the case for coverage along the central Pacific Coast of the U.S. on day 6 (Figure 2), the coast is only imaged this one day and along the western edge of the swath.

Even though MODIS-T produced considerable land coverage in the simulation, the amount of land coverage that can potentially be used in surface directional reflectance studies is somewhat less due to the lack of multiple coverage and/or limited sun-surface-sensor geometries. This situation is best shown by example at this point.

Several sites were chosen for their location and research efforts that have been conducted at them to demonstrate the potential of MODIS-T to acquire multiple images of a location from different sun-surface-sensor geometries. Sites chosen were: the Konza Prairie (First ISLSCP Field Experiment, FIFE, site), 39°N, 96°W; the Oregon transect, 45°N, 120-124°W; West Africa Sahel, 15°W, 15°N; Sudan Sahel, 15°N, 30°E, and Rondonia, Brazil, 10°S, 62°W (Locations are approximate). These sites were located on the daily land coverage maps (Figures 4-20,for a 16 day cycle) and the number of times imaged, and position relative to sub-satellite track, tabulated (Table 1).

Table 1
MODIS-T multiple image coverage of chosen sites. Percentage given at bottom of the table is the percentage of orbits that imaged a site. (N-site not imaged, Y-site imaged; location of site relative to sub-satellite track: W-west, E-east, C-center.)

	Konza Prairie		Oregon transect		West Africa Sahel		Sudan Sahel		Rondonia Brazil	
Day	Imaged		Imaged		Imaged		Imaged		Imaged	
1	N		N		N		N		N	
2	Y	W	N		N		Y	E	Y	W
3	Y	E	N		N		N		N	
4	Y	W	N		N		Y	C	N	
5	Y	E	N		N		N		Y	C
6	N		N		Y	W	Y	C	N	
7	Y	E	N		N		N		Y	C
8	N		N		N		N		N	
9	Y	W	N		N		N		Y	W
10	N		N		N		Y	E	N	
11	Y	W	N		N		Y	E	Y	W
12	Y	E	N		N		N		Y	E
13	Y	W	N		Y	W	Y	C	N	
14	Y	E	N		N		N		Y	C
15	N		Y	W	Y	W	N		N	
16	Y	C	N		N		Y	E	Y	W
	69%		6%		19%		44%		50%	

Results indicate that interior continental sites, e.g. Konza Prairie, may be imaged frequently from different platform passes, but that for sites located more towards coasts of continents, e.g. West Africa Sahel, multiple coverage begins to decline and viewing angle becomes restricted, and for sites very near the coast, e.g. Oregon transect, multiple image coverage may be non-existent.

From these results it seems that acquiring multiple MODIS-T images within some geographical regions, for the purpose of determining surface directional reflectance features, may not be very productive, or even possible, when MODIS-T is maximized for ocean coverage. In addition, some land areas, e.g. Scandinavia, the southern tips of South America and Africa, are never covered. Also it needs to be kept in mind that changes in orbital or scanner simulation parameters may alter the results observed here.

MODIS-T Composite Mode

With MODIS-T in composite mode both ocean and land surfaces can be imaged within the same scan. This may increase the potentially usable MODIS-T coverage of land for determining surface directional characteristics, yet this coverage will be constrained to the ocean tilt strategy of MODIS-T, assuming that the tilt strategy is such that ocean coverage is maximized. Thus, there may be more MODIS-T coverage of land surfaces but this coverage may be confined to a limited range of viewing geometries. The change in mode from dual to composite does not alter the tilt strategy which is assumed to remain in a "CZCS tilt strategy"--unless the scan is devoid of ocean pixels. This restricts locations at which the MODIS-T tilt could be changed to a land tilt strategy. With this restriction on tilt strategy, land coverage of of selected sites in Table 1 now represents multiple image coverage with the added option of multiple tilts.

A Simulated MODIS-T Tilting Strategy for Stare Mode over Land

For the purpose of determining land surface directional reflectance characteristics and building a BRDF, imaging of the same location from many different sun-sensor-target viewing geometries is required, thus a separate MODIS-T tilting strategy for land is desirable. It is assumed that the priority tilt strategy for MODIS-T will be for ocean coverage, i.e. a "CZCS tilt strategy", and that the tilt can only be changed to a land tilt strategy when there are no ocean pixels in a scan. Changing the MODIS-T tilt from ocean tilt to land tilt and back to ocean tilt, without losing any ocean coverage, while maximizing the collection of land directional reflectance data for the purpose of building a BRDF, requires that locations that tilt changes can be performed be determined.

Determination of locations where tilt can be changed, given ocean tilt and coverage are top priority, and what land area is potentially imaged requires that two sets of location limits be determined. First it must be determined at what point along an orbit that there is no more ocean imaged and at that point switching the tilt of MODIS-T to a land tilt at what location does land coverage begin. Second at what location must the tilt be switched back to ocean tilt to pick up the first ocean pixel in a scan, this will determine the last land location imaged in land tilt as MODIS-T is tilted to image the first upcoming ocean pixel.

Although many tilting strategies are possible for obtaining data on surface directional reflectance for building a BRDF only one has been simulated here. The specific question that this simulation was designed to answer is: What land areas can be imaged in stare mode at ±50° tilt by MODIS-T when it is not required to tilt for ocean coverage? In stare mode MODIS-T stares at specific location from a forward tilt angle rolling over to a backward tilt angle as the platform passes over the location. This simulation was performed for a ±50° tilt, the tilt limit for MODIS-T, to determine the potential land locations that may be imaged with this strategy.

Stare Simulation Results

Have not been satisfactorily produced yet. This is a very difficult scenario to simulate.

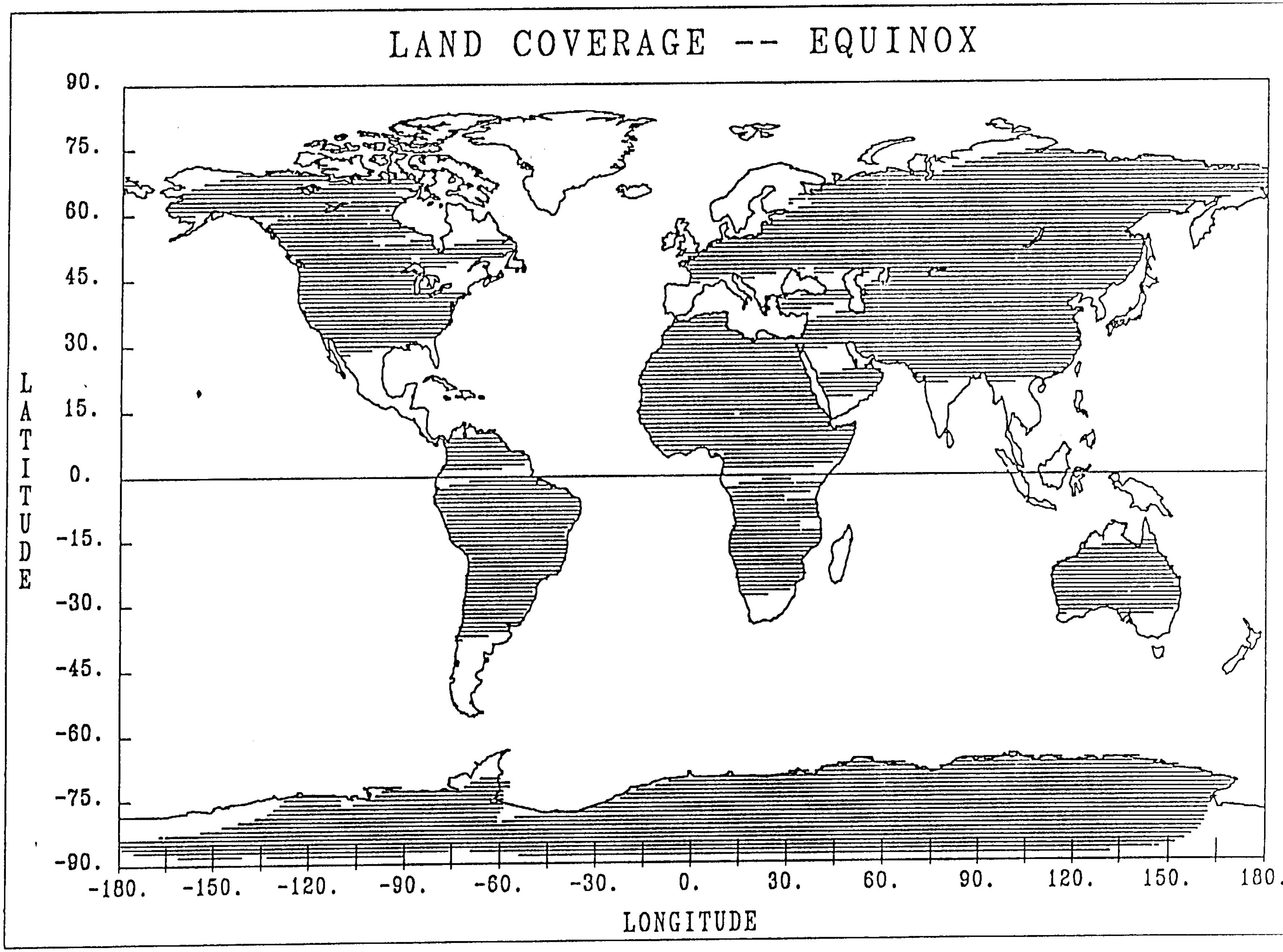
LAND COVERAGE -- EQUINOX
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 1

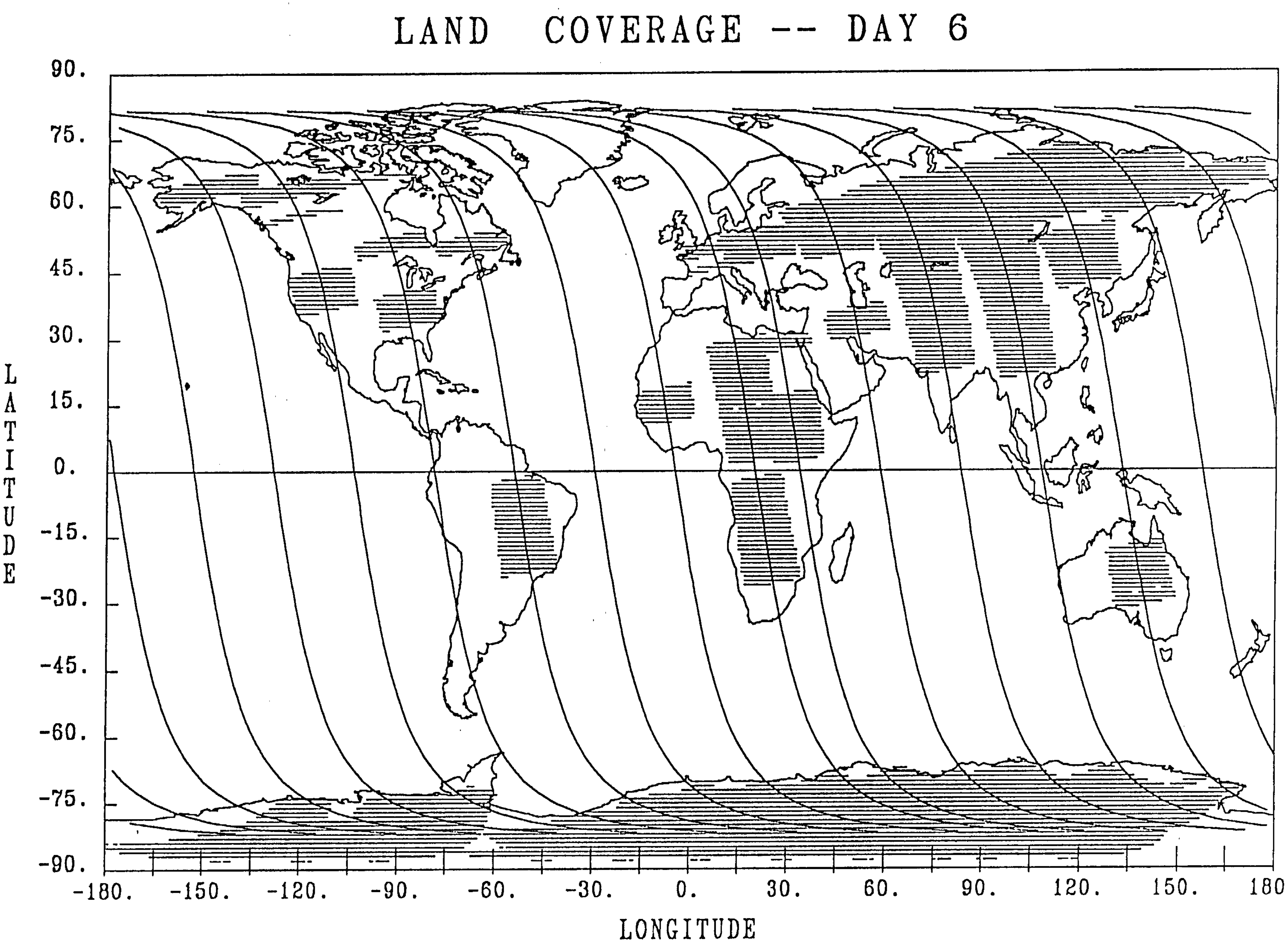
LAND COVERAGE -- DAY 6
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 2

SIZING OF CLOUD FLAGGING PROCEDURES

At this time, it is anticipated that a series of relatively simple tests will be used to distinguish clear pixels from those pixels with clouds and/or snow and ice. A second series of test will be performed to separate clear, partly cloudy, and snow or ice covered pixels. The following sizing estimates are based on the type on processing that is expected. Exactly which tests will be used and what test will be done is yet to be defined by the MODIS Science Team.

The clear pixel identification could be done using the reflected channels 2, 12, and 16 during the day; the emitted channels 31 and 32 both day and night; and channel 20 during the night only. These tests will be done for each individual field of view.

Channels 12 and 16 will each be converted from radiance to reflectance in approximately 10 operations (D0 = 20 ops). The channel 16 reflectance will be compared to that expected from a surface reflectance map which may require 20 operations (D1 = 20). The ratio of reflectance in channels 12 and 16 will be calculated and compared to threshold values which may require 10 operations (D2 = 10). The standard deviation on the 16 values from channel 2 for a single footprint will be calculated and compared to a threshold. This may require approximately 80 operations (D3 = 80). For sizing, the assumption is made that a fourth test will be done which is comparable in complexity to D3, i.e., D4 = 80 operations.

Channels 31 and 32 will each be converted to brightness temperatures which requires approximately 20 operations (B0 = 40). The channel 32, 12μm, temperature will be compared to a threshold temperature which is expected to be obtained from previous observations. This could require approximately 10 operations (B1 = 10). The standard deviation of the channel 31 temperatures is calculated over nine observations and flagged if large. This is expected to require approximately 10 operations (B2 = 10) per observation. The difference in the two channels is compared to a threshold which is calculated from the 11μm temperature and the solar zenith angle. This may require 30 operations (B3 = 30). For sizing it is assumed that a fourth test will be done similar in complexity to D3, i.e., B4 = 80 operations.

The night tests will involve channel 20 which will be converted to brightness temperature (N0 = 20). The difference between the three channels will be used for three different test each of which is expected to require approximately 10 operations (N1 = N2 = N3 = 10). For sizing it is assumed that the TBD fourth night test requires 80 operations (N4 = 80).

The total of these tests for each field of view is then

B0 + B1 + B2 + B3 + B4 + (D0 + D1 + D2 + D3 + D4) * 0.4
+ (N0 + N1 + N2 + N3 + N4) * 0.6 = 332 FLOP/field of view

where the factors 0.4 and 0.6 represent the fraction of day and night observations.

The fields of view which have one or more bits set to one by these tests will have cloud cover, snow or ice, and other types of irregular surface. An additional series of test will be done to distinguish those FOVs with uniform clouds from partly cloudy pixels and from snow and ice coverage. It is assumed that approximately 60% of the FOVs will be further processed. (It is assumed that coastal regions will be identified by geography flags and processed separately.)

The partly cloudy tests are much like the cloud test with different thresholds. For sizing purposes, it is assumed that the set of test are equivalent to B1, D1, D2, N2, and N3. This is equivalent to approximately 40 operations per cloudy FOV.

The snow/ice tests will be somewhat different. The first test to be done both day and night is a simple temperature threshold test which will require approximately 10 operations (b1 = 10).

The day tests are expected to involve the NIR bands, perhaps 21 and 7. These bands will each be converted to reflectance at approximately 10 operations (d0 = 20). Snow and ice coverage will be identified by the spectral properties which will involve taking several ratios. It is assumed that four ratios will be calculated and tested at 10 operations each (d1 = d2 = d3 = d4 = 10). The total operations in the daytime tests is approximately 60.

It is not clear how snow and ice could be identified in night observations. For sizing purposes only, it is estimated that this will take the same number of operations as daylight processing or 60 operations per cloudy FOV. The total for snow and ice testing is then approximately 70 operations per cloudy FOV.

Both the partly cloudy and the ice/snow tests will be done for the approximately 60% of the pixels. This corresponds to an average of approximately 65 operations for all FOVs.

When the processing is done it will be necessary to pack the bits to form a single word which will be stored. This is only required for cloudy FOV since for the clear pixels all bits are zero and no packing will be needed. There will be 16 bits to be packed which will require 32 operations per cloudy FOV or an average of twenty for all FOVs.

The total estimate for clear pixel identification and the further test is

332	Clear pixel identification
+0.6*110	Cloudy pixel test
+ 0.6*32	Bit packing
417	Total average operation per FOV.

With approximately 12,000 FOVs per scan this implies approximately 5 MFLOP/scan or 4.9 MFLOPS.

Cloud Fractional Area

Cloud Fractional Area is a MODIS core product that is not yet defined. At the recent science team meeting, it was decided that this product would be produced as a statistical utility product directly from the cloud flags. The product necessary will involve area averages and hence will be generated at Level-3 as well as Level-2. The sizing of this product is included in the Level-3 sizing write-up.

Sizing Estimates for
Ancillary Data Products

Atmospheric correction for MODIS for both land and oceans requires that certain ancillary data be available. In addition, certain other ancillary data products are required as inputs for atmospheric products. At this time these are limited to

- o Surface pressure (ocean and land)
- o Wind speeds (ocean only)
- o Total ozone (ocean, land, and atmosphere)
- o Total precipitable water (atmosphere only)
- o Atmospheric temperature profiles (atmosphere only)

Precipitable water vapor may also be required for atmospheric corrections over land, but no such requirement has been formally stated.

Possible data sources for these ancillary data products are listed in Table 1.

Table 1. Possible sources of ancillary data products for MODIS.

	<u>Source</u>
Surface Pressure	NMC
Wind Speeds	SCANSCAT LAWS NMC
Total Ozone	MODIS AIRS GOMR
Total Precipitable Water	MODIS AIRS
Temperature Profiles	NMC
DEM / DTM	TBD

These data sources may be generally categorized into three areas:

- o NMC (National Meteorological Center)
- o MODIS
- o Other remote sensors

We will investigate sizing requirements not by product but by potential source to preserve generality in the estimates, especially considering that sources may change during the MODIS era.

NMC

Ancillary data from NMC analyses will likely be available on standardized Earth grids. Thus obtaining Earth-located variables will only require reading the appropriate data file for the day and time, and interpolating from satellite coordinates through this standardized grid. If we assume a 1° by 1° longitude/latitude grid, we then require reading 64,800 data points (360° longitude x 180° latitude). These can be available every six hours, so that such "read" operations may occur 4 times per day. Error checks for the existence of data at each grid point will probably not be necessary if the data formatting and transfer are performed without problem. However, to be on the safe side, including them may add two additional operations per read (an "if" statement and selection of default value if not passed). We thus arrive at $\approx$ 0.52 MFLOP per day to input NMC ancillary data.

Interpolation through the NMC gridded fields to satellite anchor point position coordinates is estimated to require bi-linear interpolation from the NMC gridded field. The Earth position coordinates (latitude and longitude) are calculable directly from the standard NMC array itself. Given a complete ancillary data set, interpolation to satellite anchor points will require 22 operations for each anchor point.

Knowlegde of surface pressure at anchor points will be sufficient for ocean purposes, since the Rayleigh calculation that requires these data is then interpolated to pixels. Since land atmospheric corrections are less demanding than ocean, this procedure will also be appropriate for land.

Knowledge of wind speeds and temperature profiles to the MODIS anchor points may also be sufficient, given the uncertainties of these variables in the NMC data. However, if data are required at individual pixels, rather than just at anchor points, there will be a substantial increase in the number of operations. We assume that cubic spline interpolation will be used to interploate values at anchor points to pixels. This requires 24 operations for set-up and 10 to actually interpolate to each pixel. These estimates, as well as those discussed above, are summarized below.

Symbols Table

	MODIS-N	MODIS-T
I = number of pixels along scan	1582	1007
J = number of pixels along track	8	30
IA = number of anchor points along scan	94	80
JA = number of anchor points along track	2	5

A. Obtaining ancillary data field

0.52 MFLOP/day
≈ 29 operations/scan

B. Interpolating to anchor points

$$= 22*IA*JA$$

Thus

MODIS-N = 4136 operations/scan
MODIS-T = 8800 operations/scan

C. Interpolating to pixels

$$\begin{aligned} N = \; & 2*IA + 1 \\ & + 24*IA \\ & + (12*I)*JA \\ & + 2*JA + 1 \\ & + (12*J)*I \end{aligned}$$

$$\begin{aligned} N = \; & 1 + 26*IA + (12*I + 2)*JA + 1 \\ & + 12*J*I \end{aligned}$$

Thus

MODIS-N = 0.19 MFLOP/scan
MODIS-T = 0.43 MFLOP/scan

Note: this analysis assumes that Earth-location (navigation) of satellite anchor points has already been performed.

MODIS

Obtaining ancillary data from MODIS is the easiest and computationally least demanding method. It merely requires reading the Level-2 data product. The data will already be in pixel-by-pixel format, ready to be used by other MODIS processing. The only potential problem is the absence of a data value at a given pixel or pixels, requiring interpolation or default values.

We thus require testing for the existence of variables at pixels. If the test is not passed, we must find the nearest pixels where values exist, and interpolate to the present pixel. This procedure will require a substantial amount of processing. We will assume here that if a certain number of pixels near the pixel in question fail the existence test, default values will be used. This number will be equal to the number of pixels along track and 1/4 the pixels along scan.

Thus we have two operations per pixel if ancillary data for the pixel are available (one to read and one to test for existence). If the test fails, which we will assume occurs 1% of the time, we then must find a nearby pixel with an existing value. We assume this will require about 25 operations, to search and bi-linearly interpolate. These operations, considering they occur 1% of the time, are negligible in comparison with the sizing of the 99% passing pixels.

These total number of operations is, then

$$N = I*J*2$$

and

MODIS-N = 0.03 MFLOP/scan
MODIS-T = 0.06 MFLOP/scan

Other Remote Sensors

If ancillary data are required from other remote sensors, estimation of the sizing requirements is extremely difficult. This is because we do not know whether MODIS will receive Level-2 or Level-3 data, in what format the data will be, and what the likelihood of missing pixels is. Perhaps the best way to assess sizing requirements from other sensors is to assume they are similar in data volume and structure as MODIS, and that they are provided as Level-2 (the minimum amount of pre-processing). Since the data will not be at the same pixel locations as MODIS, a search will have to be performed to find the corresponding locations in the remote sensor arrays to the MODIS arrays. We assume this will require about 50 operations. These 50 operations are in addition to the "read" and search operaions for missing pixels for MODIS data.

Then the total numer of operations is

$$N = I*J*2*50$$

and

MODIS-N = 1.27 MFLOP/scan
MODIS-T = 3.02 MFLOP/scan

Summary

Our best guess at the present time is that pressure and temperature profiles will be obtained from NMC, ozone and total precipitable water from MODIS, and wind speeds from SCANSCAT. Given these assumptions, and further assuming pressure and temperature data are sufficiently accurate is interpolated to MODIS anchor points, we arrive at the following estimate of sizing for ancillary data.

MODIS-N	Pressure	0.004 MFLOP/scan
	Wind Speed	1.27 MFLOP/scan
	Total Ozone	0.03 MFLOP/scan
	Total Precipitable Water	0.03 MFLOP/scan
	Temperature Profiles	0.004 MFLOP/scan
	Total	1.34 MFLOP/scan
MODIS-T	Pressure	0.009 MFLOP/scan
	Wind Speed	3.02 MFLOP/scan
	Total Ozone	0.03 MFLOP/scan
	Total	3.06 MFLOP/scan

LEVEL-3 PROCESSING

The following discussion contains an estimate of the processing required to generate the Level-3 products. All of the core MODIS products are considered. The Cloud Fractional Area product is sized for the first time here.

There is one key assumption made in generating this estimate. It is assumed that the Level-2 data can be processed "on the fly", e.g., each Level-2 datum can be individually processed. This scheme will work well as long as the processing done on a single value does not directly depend on other Level-2 data. It is not clear that this method can be applied to generate all Level-3 products. However, it does appear to be applicable to all of those products which have been considered thus far.

The processing to be done on each Level-2 datum will depend on the Level-3 product being generated. The complexity of the processing depends primarily on the resolution of the Level-3 product. The finer the resolution of the Level-3 product, the more complicated the processing on each Level-2 datum.

As an example, Level-3 ocean products will be generated with a 1 km resolution in coastal regions. A single MODIS-T observation may overlap 6 or 8 Level-3 grid points. The processing on the Level-2 datum will require rectifying the Level-2 datum to account for area of overlap and might involve weighting by such factors as distance from the grid point. As the Level-3 grid becomes larger an area correction is no longer necessary. When cloud products are generated with one degree resolution, it is not necessary to worry about the overlap of MODIS-N observations.

Additional analysis is needed to determine if this method can actually be used for all products. However, it does seem a reasonable method (which is computationally efficient). The Level-3 processing estimate which is generated does seem reasonable.

It is not known in any great detail how the Level-3 products will be generated. For sizing purposes, it is assumed that the processing to be performed on each Level-2 datum is simple, moderate, or complex with 20, 50, and 200 operations required respectively. The processing of the Level-2 data will be estimated in terms of operations per datum times the data rate. This will yield an estimate in terms of FLOPS (FLoating-point OPerations per Second).

After all of the Level-2 data has been processed and composited, additional processing will be done to generate the Level- 3 product. The processing may be very simple, e.g., divide a sum by the number of data points, or relatively complex, e.g., calculating a mean and variance from a histogram. The Level-3 processing requirement is estimated for each type of product.

All of the Level-2 data must be processed and accumulated before the additional processing can be done. The processing power required depends on how long a period is allowed for this additional processing. This sizing estimate has been generated in terms of operations per day which can be converted to FLOPS by dividing by the time allowed for the additional processing.

For each Level-3 product, or type of product, there are two processing numbers given. The first in terms of FLOPS is the processing done on the Level-2 data. The second is in terms of operations per day.

Atmospheric Products

The Level-3 atmospheric products, both clouds and clear sky, will be generated with 1 degree resolution. (The exception is aerosol products which will be generated at Level-3. i.e., no Level-2 product, with 1/2 degree resolution.) This will allow simple processing of the Level-2 data at 20 FLOP/datum.

A1 - Cloud Optical Depth, Effective Particle Radius

These products will be produced with 5 km resolution at Level-2 by selecting a subset of the Fields of View (FOV). This is roughly equivalent to processing only 1 out of 25 FOVs. The processing will be done only during the day (0.4 of the data) and only when there are clouds (0.5 of the data). The number of Level-2 data points is then (12,165 FOV/sec for MODIS-N and 6,360 FOV/sec for MODIS-T)

$$12{,}165*0.4*0.5/25 = 97 \text{ L-2 data/sec.}$$

With simple compositing at 20 ops/datum, the processing required is

<u>1950 FLOPS at L-2.</u>

1 degree resolution at Level-3 implies $4.2X10^4$ Level-3 cells (assuming equal area grid). It is assumed that the Level-3 product will be in the form of a histogram and associated statistics. This will require non-trivial processing of the Level-3 grid which is assumed to require 200 operations per cell. There will be daily, weekly, and monthly products generated. It is assumed, for this and all other products, that a weekly product requires 1/7 and a monthly product 1/30 of the processing required for a daily product. The total processing on the Level-3 cells is then

$$200*4.2X10^4*(1 + 1/7 + 1/30) = \underline{9.9X10^6 \text{ ops/day}}.$$

A2 - Cloud Water Thermodynamic Phase

Level-2 exactly as above. The Level-3 processing will be much simpler since the Level-3 product is expected to be % clear, ice, and water. The processing on the Level-3 cells is as above except that 10 operations will be sufficient. The totals are

<u>1950 FLOPS at L-2, $4.9X10^4$ ops/day.</u>

A3 - Cloud Effective Emissivity, Top Temperature, Top Height, Atmospheric Stability, Total Precipitable Water, Total

Ozone Content

It is anticipated that the processing to produce these Level- 3 products will be functionally identical. All products will be produced with 5 km resolution and 50% coverage, i.e. 0.5 clouds for cloud products and 0.5 clear for clear products. This implies

$$12,165*0.5/25 = 243 \text{ L-2 data/sec.}$$

With simple compositing at 20 ops/datum, the processing required is

<u>4850 FLOPS at L-2.</u>

The Level-3 processing is as described in A1 except that there will be both day and night products. Hence, there will be twice as many Level-3 cells and twice the processing will be done.

<u>$19.8X10^6$ ops/day.</u>

A4 - Cloud Fractional Area

This product is not currently well defined. This discussion is very preliminary and should be used for system sizing only. It has been assigned as a utility algorithm by the MODIS atmosphere working group and it is assumed that it will be generated directly from the cloud flags. It is assumed that the product will be generated at Level-3 with 1 degree resolution. Assume that a 10 element histogram will be generated, i.e., clear plus 9 cloud types. All of the Level-2 FOVs will be processed to generate separate day and night products. Assume that 50 operations per Level-2 datum are required which yields (50*12,165=)

<u>$6.1X10^5$ FLOPS at L-2</u>.

The Level-3 product will be fraction of each type which is expected to require 40 ops/L-3 grid. There will be daily, weekly, and monthly day and night products for each of day and night which will require

$$40*2*4.2X10^4(1 + 1/7 + 1/30) = \underline{4.0X10^6 \text{ ops/day}}.$$

A5 - Aerosol Optical Depth, Aerosol Size Distribution

Generated as a Level-3 daily product. A negligible amount of processing will be required to calculate weekly and monthly averages. Assume zero.

Atmospheric Total

$$2XA1 + A2 + 6XA3 + A4 = \underline{0.6 \text{ MFLOPS at L-2, } 1.4X10^8 \text{ ops/day}}.$$

Ocean Products

The Level-3 ocean products will be a 1km resolution local daily product, a 4km regional weekly product, and a 20km monthly global product. Assume that the 1km/4km/20km regions cover 10%/30%/70% of the globe (14%/43%/100% of the ocean) which will require $5.1X10^7/9.5X10^6/8.9X10^5$ grid cells. The 1km/4km/20km processing on the Level-2 data is expected to require 200/50/20 operations per Level-2 datum. Assume that the Level-3 products will take the form of averages (mean, standard deviation, etc.) which will require 20 operations per Level-3 cell.

O1 - Chlorophyll, Chlorophyll Florescence, Pigment Concentration, Attenuation @ 490, Detached Coccoliths, Dissolved Organic Matter, Phycoerythrin, Single Scattering Aerosol Radiance, Angstrom Exponents, Total Seston (10 total)

All of these products are expected to undergo similar Level-3 processing. Both N and T will be used. Assume 0.5 for clear sky and 0.4 for daylight. The Level-2 operations are

```
   1km 200*[0.1*12,165(N) + 0.1*6,360(T)]*0.5*0.4
+ 4km   50*[0.3*12,165 + 0.3*6,360]*0.5*0.4
+20km   20*[0.7*12,165 + 0.7*6,360]*0.5*0.4  =
```

$\underline{1.8X10^5 \text{ FLOPS at L-2}}$.

The processing of the Level-3 cells requires

$20*(5.1X10^7 + 9.5X10^6/7 + 8.9x10^5/30) = \underline{1.0X10^9 \text{ ops/day.}}$

O2 - Sea Surface Temperature, Sea Ice (Overestimate for Ice)

These products will use N only both day and night. Otherwise, the processing will be as above. It is assumed that day and night observations are combined is a single Level-3 product. The total requirements are

$\underline{2.9X10^5 \text{ FLOPS as L-2, } 1.0X10^9 \text{ ops/day}}$.

O3 - Water Leaving Radiance

The assumption is made that 9 MODIS-N bands and 15 MODIS-T bands will be processed to Level-3. The processing on the Level-2 data is as in O1 except the number of FOVs is 9*12,165 and 15*6360. The processing on the Level-3 cells is as in O1 except there are 24 products. The totals are

$\underline{2.0X10^6 \text{ FLOPS at L-2, } 2.4X10^{10} \text{ ops/day}}$.

O4 - Primary Production

This product is assumed to be produced at Level-3 and the processing requirement is neglected.

Ocean Total

$$10*01 + 2*02 + 03$$

<u>4.1 MFLOPS at L-2, $3.5X10^{10}$ ops/day.</u>

Land Products

These products will be generated using MODIS-N only. The appropriate factors are 0.3 for land, 0.5 for clear sky, and 0.4 for day (except snow and temperature). It is assumed that all products will be generated with 10 km resolution which implies $5.1X10^6$ Level-3 cells. For all products, there will be weekly and monthly averages (histograms for NDVI) plus daily products for radiance, reflectance, and temperature.

L1 - Land Leaving Radiance, Surface Reflectance

It is assumed that 3 visible 856 m and 1 visible 428 m channel will processed to Level-3. Assume 50 operations per Level-2 datum. The processing requirement is

$50*(3*12,165 + 4*12,165)*0.3*0.5*0.4 =$ <u>$2.6X10^5$ FLOPS at L-2</u>.

Assume that the averages take 20 operations per Level-3 cell. With 4 products the total is

$4*20*5.1X10^6*(1 + 1/7 + 1/30) =$ <u>$4.8X10^8$ ops/day</u>.

L2 - NDVI

The Level-2 product will be generated form the 256m channels. It is assumed that simple compositing which requires 20 operations per datum is sufficient. The requirement is

$20*(16*12,165)*0.3*0.4*0.5 =$ <u>$2.3X10^5$ FLOPS at L-2</u>.

Assume only weekly and monthly products are produced. The Level- 3 product is expected to be histogram and statistics which will require 200 operations per Level-3 cell. The requirement is

$200*5.1X10^6*(1/7 + 1/30) =$ <u>$1.8X10^5$ ops/day</u>.

L3 - Surface Temperature

The assumption is made that this product is generated both day and night and that 50 operations per Level-2 datum are required. This implies

$50*12,165*0.3*0.5 =$ <u>$9.1X10^4$ FLOPS at L-2</u>.

Separate day and night products will be generated daily, weekly, and monthly with the averaging requiring 20 operations per Level- 3 cell. This implies

$20*(2*5.1x10^6)*(1 + 1/7 + 1/30) =$ <u>$2.4X10^8$ ops/day</u>.

L4 - Snow Cover

Assume that both day and night data will be processed but that only 0.5 of the surface can have snow cover. Assume 50 operations per Level-2 datum.

$$50*12{,}165*0.3*0.5*0.5 = \underline{4.6X10^4 \text{ FLOPS at L-2}}.$$

Assume day and night data are combined in the Level-3 product which will be produced weekly and monthly but only cover 0.5 of the land surface. Assume 20 operations per Level-3 cell to generate averages.

$$20*(0.5*5.1X10^6)*(1/7 + 1/30) = \underline{9.0X10^6 \text{ ops/day}}.$$

L5 - Land Cover

Assume generated at Level-3, perhaps 2-4 times per year. Assume a negligible processing requirement.

L6 - Thermal Anomalies

This product could be a list of locations. As such, no level-3 processing would be required.

Land Total

$$2*L1 + L2 + L3 + L4$$

$\underline{0.9 \text{ MFLOPS at L-2, } 1.2X10^9 \text{ ops/day}}$.

Total

(1) 5.6 MFLOPS at L-2

(2) $3.6X10^{10}$ ops/day, (This is 10.1 MFLOPS if Level-3 data is generated within one hour after the compositing is finished.)

The total would be 15.7 MFLOPS, assuming the hypothetical computationally efficient Level-2 to Level-3 algorithms discussed above are used.